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Beam Diagnostics by Thomson Scattering with the Tokyo-EBIT

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Abstract

We have measured the electron beam radius with the Tokyo-EBIT using a Thomson scattering method. Dependences of the beam radius were investigated on beam energy, beam current and magnetic field at the center region of the trap. The variations of the measured beam radius against the beam current and the magnetic field were similar to those in the Herrmann's prediction. However, it is seemed that the beam radius was dependent on the beam energy, which is different from the theory.

1. Introduction

The electron beam ion trap (EBIT) has been developed for studying the physics of highly charged high-Z ions [1,2]. An EBIT consists of a magnetically compressed electron beam with high current density passing through a series of drift tubes. Ions are confined radially by the space charge of the electron beam, axially by applied voltages to the drift tubes, and ionized successively by collisions with electrons. In addition to ionizing ions, the electron beam interacts with the trapped ions in such ways as excitations and (dielectronic) recombinations. In order to estimate the cross sections for electron-ion interactions such as especially that for ionization processes [3], it is important to measure the current density of the beam which can be obtained from the measurement of the radial intensity profile at the trap region. Knapp *et al.* measured the radial size of the source of X-ray radiation in the super-EBIT [4] using an X-ray pinhole camera.

Theoretical consideration for the radial profile of the magnetically compressed electron beam was developed by Herrmann [5]. The semi-empirical description for the electron beam radius r_h in a magnetic field $\boldsymbol{B}$ is given by

$$r_h = r_{\rm b}\sqrt{\frac{1}{2}+\frac{1}{2}\sqrt{1+4\left(\frac{8kTr_{\rm c}^2}{m\eta^2 r_{\rm b}^4 B^2}+\frac{B_{\rm c}^2 r_{\rm c}^4}{B^2 r_{\rm b}^4}\right)}}, \tag{1}$$

where r_h is the effective beam radius, defined as the radius containing 80% of the beam current, $r_{\rm c}$ is the cathode radius, kT the electron temperature at the cathode, $B_{\rm c}$ the magnetic field strength at the cathode, m the electron mass and η is the electron's charge to mass ratio. $r_{\rm b}$ is the beam radius for Brillouin flow given in μm by:

$$r_{\rm b} \approx \frac{150}{B}\frac{\sqrt{I_{\rm e}}}{(E_{\rm e})^{1/4}}. \tag{2}$$

Here $I_{\rm e}$ is the electron current in the beam in Amperes, B the magnetic field strength at the trap in Tesla and $E_{\rm e}$ is the electron beam energy at the trap in keV.

From Eq. (1), at low electron temperatures and $B_{\rm c} = 0$, the beam radius varies only weakly with energy: $E_{\rm e}^{-0.06}$. However, according to the observation of X-ray images at the Livermore EBIT the beam radius changed with beam energy [6].

In this paper, we describe the systematic measurement of the beam radius using the Thomson scattering system [7] as functions of beam energy, beam current and magnetic field at the trap.

2. Experimental setup

The Tokyo-EBIT [8–10] is designed to operate at a maximum beam energy of about ~300 keV. The device consists of three parts; an electron gun, a cryostat region including drift tubes and an electron collector. The gun and the collector float at a high negative voltage up to −300 kV. The electron beam is accelerated from the gun into the drift tubes whose maximum voltage is +40 kV and is compressed by an axial magnetic field with super-conducting Helmholz coils. The beam radius is minimized at a condition of $B_{\rm c} = 0$, which is produced by using a bucking coil located at the cathode position.

The measurement of the beam profile is based on the observation of Thomson scattering of laser light by the electron beam. As compared with the similar measurements

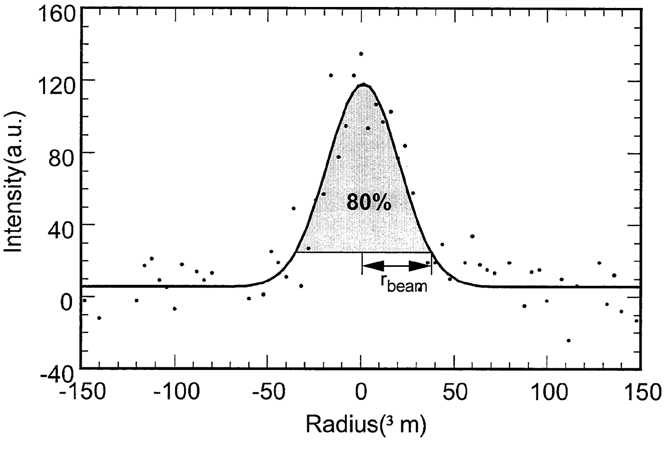

Fig. 1. Thomson scattering profile by the electron beam; 15 keV, 140 mA. The shaded area encloses 80% of the electron beam current. The best fit to a Gaussian profile gives an 80% radius $r_{\rm beam}$ of 36.7 μm.

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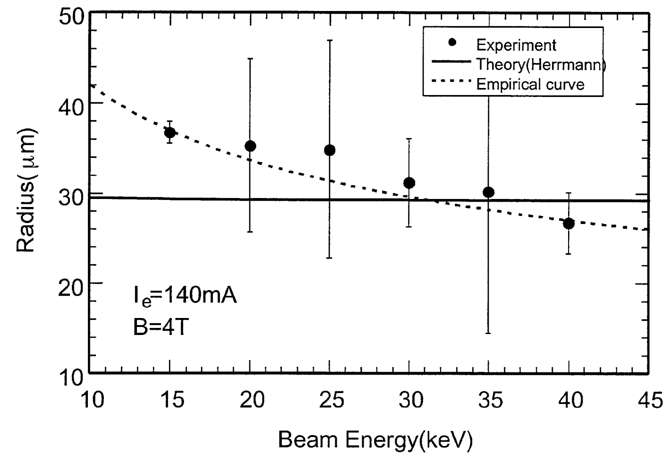

Fig. 2. The beam radius as a function of the beam energy.

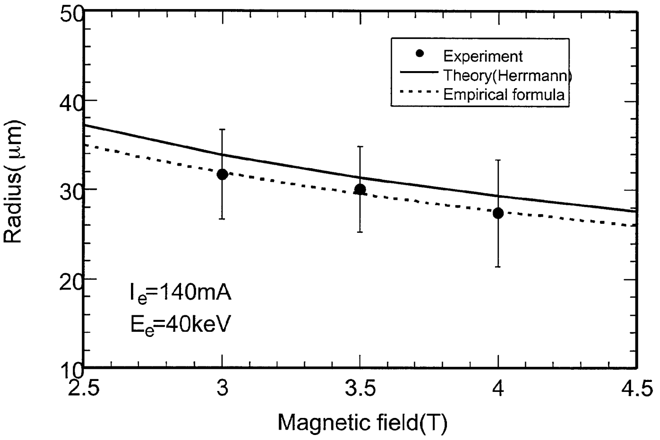

Fig. 4. The beam radius as a function of the magnetic field at the trap.

by observation of radiation source image from trapped ions, the present measurement could give us, in principle, direct information for the electron beam profiles. Therefore, in the present experiment, we would like to demonstrate the feasibility of this method using Thomson scattering.

The laser source is a diode-pumped, frequency-doubled Nd : Vanadate laser (Nd : YVO_4 , COHERENT Verdi) that provides single-frequency green light ($\lambda = 532$ nm) at output power levels of 0.5 ~ 6 W. A laser beam was injected downwards into the center of the drift tube from the top of the EBIT. The alignment of the laser axis which was very important in this experiment, was performed by using a fine adjustable dichroic mirror and a transit telescope [7].

Photon signals by Thomson scattering were observed at $\theta = 90^\circ$ with respect to the laser beam axis. The photon detector, which is a charge coupled device (CCD) camera (Princeton Instruments, LN/CCD-1300EB-GI) has a 1340 × 1300 pixels array with a 20 μm pixel size. The magnification of this system is approximately 5×, that is, the spatial resolution is 4 μm. A 100-mm diameter achromatic fused silica lens with a focal length of 150 mm was located at 347 mm from the electron beam axis of the EBIT.

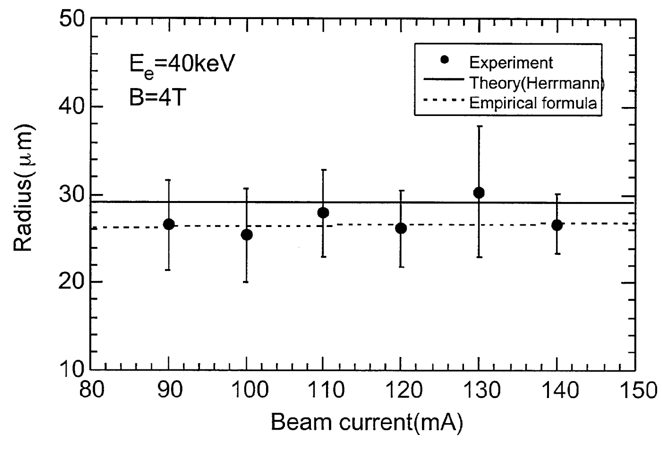

Fig. 3. The beam radius as a function of the beam current.

Three kinds of filters were used to select wavelengths in the Thomson scattering signals, which consisted of two color glasses (HOYA B-390, MELLES GRIOT KG-3) and an interference filter (SIGMA KOKI DIF-50S-BLE). In order to improve signal to noise ratios, photon signals were measured both with and without the electron beam. True signals due to Thomson scattering were obtained by a subtraction method. When true signal levels were low, experimental data in the same measurement repeated were accumulated. A large number of accumulations gave good statistics.

3. Results and discussion

The beam image was displayed on the CCD camera by measuring Thomson scattering signals by the electron beam. The intensity profile of the electron beam was obtained by fitting to a Gaussian profile. Figure 1 shows the Thomson scattering profile at beam conditions of 15 keV, 140 mA and a magnetic field at the trap of 4 T. From the best fit of the image, an 80% beam radius was obtained to be 36.74 ± 1.18 μm as shown in the figure.

We have investigated dependences of the beam radius on the beam energy, the beam current and the magnetic field at the trap. Figure 2 shows the measured beam radius as a function of the beam energy. In this measurement the beam current is fixed at 140 mA and the magnetic field at the trap is 4 T. In this figure, closed circles show the experimental values and a solid line indicates the calculation by Herrmann's theory. The wide error bars at beam energies of 20, 25 and 35 keV come from poor statistics due to only a few times of accumulations for the measurements, while a small error bar is shown at the 15 keV-beam due to ten times accumulation procedures. The experimental data at 30 and 40 keV are obtained after a five times accumulations. Figures 3 and 4 are the measurements of the beam radius as a function of the beam current and the magnetic field, respectively. In Fig. 3 the beam energy was 40 keV and the magnetic field at the trap 4 T. In Fig. 4 the beam conditions were 40 keV, 140 mA.

As shown in Figs. 3 and 4, the measured beam radius shows a similar dependence on the beam current and the magnetic field as Herrmann's theory. However, the beam radius seems to become larger with decreasing energy, that is, the beam radius might be dependent on the beam energy, which is different from Herrmann's theory. Then, although the experimental data were scattered we obtained an empirical fitting curve for the energy dependence of the beam radius, which is proportional to $E_e^{-0.5}$, as shown by a broken line in Fig. 2. This empirical formula reproduces well the measured values for the current- and magnetic field-dependences of the beam radius.

It is not clear that the beam radius has stronger dependence on the energy than that for Herrmann's theory. In order to understand the characteristics of the electron beam in the EBIT, it is necessary to accumulate more accurate data for various beam energies, and also to investigate other parameter-dependences such as kT and B_c.

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References

1. Levine, M. A. *et al.*, Physica Scripta **T22**, 157 (1988).
2. Marrs, R. E., Levine, M. A., Knapp, D. A. and Henderson, J. R., Phys. Rev. Lett. **60**, 1715 (1988).
3. Sokell, E. *et al.*, Physica Scripta **T80**, 289 (1999).
4. Knapp, D. A. *et al.*, Nucl. Instrum. Meth. Phys. Res. A **334**, 305 (1993).
5. Herrmann, G., J. Appl. Phys. **29**, 127 (1958).
6. Utter, S. *et al.*, Livermore EBIT 1996-1997 Annual Report, p. 102.
7. Kuramoto, H. *et al.*, Proc. XXI. ICPEAC, vol. 1, p. 175 (1999).
8. Currell, F. J. *et al.*, J. Phys. Soc. Jpn. **65**, 3186 (1996).
9. Nakamura, N. *et al.*, Physica Scripta **T73**, 368 (1997).
10. Kuramoto, H. *et al.*, Rev. Sci. Instrum. **71**, 687 (2000).